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(54) REFRIGERANT FOR A CRYOGENIC THROTTLING UNIT

(71) We, NAUCHNO-ISSLEDOVATELSKY INSTITUT KRIOGENNOI ELEKTRONIKI, of Kiev, 50, Union of Soviet Socialist Republics, a company organised and existing under the laws of the Union of Soviet Socialist Republics, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a refrigerant for a cryogenic throttling unit, and to a method of attaining low or cryogenic temperatures, and may find various applications, for example in cooling electronic devices and thermostatting various objects.

There are known methods of cooling objects to low temperatures, including the liquefaction temperature of nitrogen, in low temperature units operating on a regenerative cycle involving refrigerant throttling. In such units use is made of nitrogen and argon, for example, as refrigerants.

The refrigerant is subejcted to compression in a compressor and directed to the high-pressure side of a regenerative heat exchanger which is arranged in a cryostat, and the refrigerant is throttled through the throttle orifice of the heat exchanger, whereupon the refrigerant comes to the low-pressure side of the heat exchanger and absorbs heat from the object being cooled.

The known methods of cooling which involve the use of the aforementioned refrigerants suffer from a number of disadvantages such as a relatively low thermodynamic efficiency, i.e. high consumption of energy per heat unit abstracted from the object to be cooled, the thermodynamic efficiency being primarily dependent upon the magnitude of the isothermal integral throttling effect for a given refrigerant. A further disadvantage is the necessity of using in known low temperature units high-pressure refrigerants (about 100-300 kg/cm^2), thereby shortening the service life of such units. The known low temperature units for carrying out such methods of cooling are also disadvantageous in that their performance reliability is low due to the fact that impurities, such as for example carbon dioxide and oil vapours, in refrigerants are likely to freeze out in the regenerative heat exchanger and to clog the throttle orifice.

In low temperature units operating on a regenerative cycle involving refrigerant throttling, substances used as refrigerants should have a relatively low isothermal integral throttling effect in order to attain the desired cooling temperature.

The use of agents noted for their high throttling effect does not make it possible to attain the desired cooling level when the pressure of such agents downstream of the throttle is either equal to or less than the pressure of known refrigerants, since the cooling temperature would be limited by the temperature at which a solid phase appears in such agents.

The invention consists in a refrigerant comprising a first component and at least one other component having a higher isothermal integral throttling effect and a higher boiling point than the said first component, wherein the said other component(s) has a solidification point above the boiling point of the said first component at atmospheric pressure. The present invention also consists in a method of cooling objects to low temperatures, comprising compressing a refrigerant according to the previous paragraph, cooling the refrigerant in a regenerative heat exchanger, throttling the refrigerant, passing the refrigerant to an object to be cooled, and heating the refrigerant in the regenerative heat exchanger. The concentration of the components is selected so as to obtain, after throttling, a mixture of the first component

and the other components in the liquid-vapour state and also to cool the objects to a temperature which is close or equal to the cooling temperature provided by the first component only.

Such a method of cooling objects to low temperatures exhibits a superior thermodynamic efficiency as a result of employing a refrigerant having a higher isothermal integral throttling effect.

There may be incorporated into the original refrigerant components which are soluble in the refrigerant at the boiling point thereof under atmospheric or sub-atmospheric pressure, thereby excluding the formation of a solid phase in the liquid on passage through the throttle of the cryogenic unit, thus providing for trouble-free operation. For example solid methane is soluble in liquid nitrogen over a wide range of pressures and temperatures. When use is made of a "nitrogen-methane" mixture containing 50% by volume of methane, the efficiency of the low temperature unit will be approximately doubled, though the cooling temperature obtained with such a nitrogen-methane mixture is somewhat higher and is approximately 82°K compared with a cooling temperature of approximately 78°K attained with nitrogen alone.

It is preferable to incorporate into the original refrigerant components which are practically insoluble in the refrigerant at the boiling point thereof at atmospheric or sub-atmospheric pressure. Suitable selection of the concentrations of such components makes it possible to ensure that a solid phase in the liquid mixture is not formed downstream of the throttle, the absence of solid phases under such conditions being vital for normal operation of low temperature units according to the invention.

The concentration of such components is elected so that the temperature of solid phase (eutectic mixture) formation in the mixture will be less than the solidification temperature of each substance used and also less than the boiling point of the original refrigerant under atmospheric or sub-atmospheric pressure. If this condition is observed, the liquid, on passage through the low temperature unit throttle, consists of two liquid phases, one liquid phase being the liquefied original refrigerant, and the second liquid phase consisting of the eutectic mixture of the components and th original refrigerant dissolved therein.

The cooling temperatures provided by the low temperature unit, in which the working substance consists of the mixture of the original refrigerant with the added components, is governed by the boiling point of the liquid phase consisting of the liquefied original refrigerant and is, therefore, equal to the cooling temperature attained when use is made of the original refrigerant only in the low temperature unit.

Insofar as the selection of the components introduced into the original refrigerant is dictated by the requirement of using components noted for their higher isothermal integral throttling effect, the resulting mixture of the original refrigerant and the components introduced therein would have a higher isothermal integral throttling effect compared to the effect produced by the refrigerant only.

Thus, for example, ethane and propane are practically insoluble in liquid nitrogen, and each of these components alone is solid at the liquefaction temperature of nitrogen, but ethane and propane in specific proportions afford an ethane-propane mixture which remains liquid at the boiling point of liquid nitrogen at atmospheric pressure.

In low temperature units use may be made of a "nitrogen-ethane-propane" mixture of the following composition, % by volume: nitrogen 30-70; ethane 35-15, and propane 35-15.

The use of a "nitrogen-ethane-propane" mixture containing 40% by volume nitrogen, 30% by volume ethane and 30% by volume propane as the working substance made it possible to attain a 5- to 7-fold increase in the efficiency of the low temperature unit compared with the efficiency of a unit using nitrogen only as the refrigerant, an added advantage being that the cooling temperature attained with such a mixture is about 78°K and equals that attained with nitrogen only.

Into the original refrigerant there may be introduced components selected so that the solidification point of each component is above the boiling point of the initial refrigerant and that the liquid mixture, after throttling, does not contain a solid phase. The latter is obtained by selecting the components so as to incorporate into the original refrigerant at least one component soluble in the refrigerant at the boiling point thereof under atmospheric or sub-atmospheric pressure, the other components being insoluble in the original refrigerant, but soluble in the one component.

By using suitable concentrations it is possible to avoid the formation of a solid phase in the liquid which has passed through the low temperature unit throttle.

The liquid, on being throttled, consists of a plurality (from 2 to 4) of liquid phases containing all the components of the mixture in various concentrations. The cooling temperature attained in the low temperature unit depends on the initial boiling point of the lowest-boiling liquid phase,

this phase being the one containing the highest proportion of the original refrigerant.

Since the components introduced into the original refrigerant are noted for their higher throttling effect, the overall throttling effect of the resultant mixture is essentially above that of the original refrigerant.

For example, in a "nitrogen-methane-ethane" mixture, the original refrigerant is nitrogen, and methane is soluble in nitrogen while ethane is insoluble in nitrogen but soluble in methane. The mixture may have the following composition, % by volume: ntirogen 70-20; methane 20-40, and ethane 10-40.

The use of a "nitrogen-methane-ethane" mixture containing 30% by volume nitrogen, 35% by volume methane and 35% by volume ethane as the working substance resulted in a 6- to 9-fold increase in the efficiency of the low temperature unit compared with the efficiency of the unit using nitrogen only as the refrigerant. With such a mixture as the refrigerant, the cooling temperature attained in the low temperature unit was approximately 79.5°K, compared with a cooling temperature of approximately 78°K when use is made of nitrogen only.

It is also expedient to use a "nitrogen-methane-ethane-propane" mixture having the following composition, % by volume: nitrogen 70-20; methane 10-30; ethane 10-25, propane 10-25. A "nitrogen-methane-ethane-propane" mixture containing 30% by volume nitrogen, 30% by volume methane, 20% by volume ethane, and 20% by volume propane afforded a 10- to 12-fold increase in the efficiency of the low temperature unit compared with the efficiency of the unit using nitrogen only as the refrigerant. With the mixture the cooling temperature attained was approximately 80°K, compared with a temperature of approximately 78°K attainable with nitrogen only.

To all the mixtures described above there may be added at least one component which exhibits, under identical conditions, a lower isothermal integral throttling effect and a lower boiling point that does the original refrigerant, such a component having a solidification point below the boiling point of the original refrigerant under atmospheric or sub-atmospheric pressure. Such components are selected so as to attain in a low temperature unit using the resulting mixture a cooling temperature below that attainable with the original refrigerant only.

Such components are neon, hydrogen or helium taken either singly or in combinations in an amount of from 5 to 40% by volume.

Thus, for example, a "nitrogen-methane-ethane-propane-neon" mixture containing 25% by volume nitrogen, 25% by volume methane, 15% by volume ethane, 15% by volume propane, and 20% by volume neon when used as the working substance in the low temperature unit afforded a cooling temperature of approximately 63°K, whereas with nitrogen as the working substance the temperature obtained was approximately 78°K.

In low temperature units operating on a regenerative cycle and involving nitrogen throttling, the initial throttling pressure is 100-200 kg/cm². Decreasing the initial pressure of nitrogen throttling below 70 kg/cm² results in a marked decrease in the throttling effect exhibited by nitrogen. In contrast, the mixtures described hereinbefore are such that, when throttled at an initial pressure of about 50 kg/cm², a significant throttling effect is produced which ensures effective operation of the low temperature units.

Initial throttling pressure depression that accrues from the use of the aforementioned mixtures is conducive to increasing the service life of low temperature units.

Impurities present in the original refrigerant in the course of time freeze out in the regenerative heat exchanger and tend to clog the throttle orifice. The use of the aforementioned mixtures as the working substance in low temperature units is advantageous in that impurities such as carbon dioxide and oil vapours are soluble in such mixtures and do not clog the throttle orifice, whereby the performance reliability and continuous service life of low temperature units are increased.

In contrast to the use of nitrogen only, the use of the aforementioned mixture as refrigerants in low temperature units is particularly beneficial where objects being cooled generate heat. While heat influx to such objects due to heat insulation imperfections lends itself to redistribution so as to increase the share of heat influx at a higher temperature level, the use of the aforementioned mixtures as refrigerants in low temperature units results in a further improvement in the efficiency of low temperature units.

The invention will be further described by way of example only, with reference to the accompanying drawings, in which:—

FIGURE 1 is a schematic view of a low temperature unit.

FIGURE 2 is an enlarged view of a part of the low temperature unit according to Figure 1;

and FIGURE 3 is a vertical section through a low temperature unit.

The low temperature units shown in the drawings may suitably use the mixtures de-

scribed above.

The low temperature unit shown in Figure 1 includes a reciprocating compressor 1 for pressurising the refrigerant used, a cryostat 2 with vacuum thermal insulation and a built-in regenerative heat exchanger 3. The high-pressure side 4 (Figure 2) of the heat exchanger 3 is the inner volume of a tube 6 wound onto a core 5, while the low-pressure side 7 of the heat exchanger 3 is constituted by the intertubular space between the core 5 and cryostat cartridge 2.

The high-pressure side 4 and the low-pressure side 7 are connected by means of throttle orifice 9 (Figure 1).

The cryostat 2 includes heat shields 10 and 11, which surround an object to be cooled 12. In each heat shield provision is made for a coil 13, 14, while the low-pressure side 7 of the heat exchanger 3 is divided into three compartments by partitions 15, these compartments being connected in series by means of coils 13 and 14.

The low temperature unit operates as follows.

The refrigerant is compressed in the compressor 1 and directed via a high-pressure line 16 to the high-pressure side 4 of the heat exchanger 3, in which the refrigerant undergoes cooling and is throttled via the throttle orifice 9, abstracts heat from the object being cooled 12 and passes to the low-pressure side 7 of the heat exchanger 3. The partitions 15 are so arranged that the refrigerant is directed successively to the coils 13 and 14. While flowing through the coils 13 and 14, the refrigerant absorbs heat from the heat shields 10 and 11 which are at a higher temperature than the cooled object 12, whereby the influx of heat to the object 12 is reduced at a low-temperature level. From the low-pressure side 7 the refrigerant passes via a low-pressure line 17 to the compressor 1, whereupon the refrigerant is compressed and recycled.

In order to use low temperature units of this type for cooling heavy objects and also to minimising heat losses associated with the intensive heat absorbed from the object being cooled by the refrigerant during the starting period of the low temperature unit, in the cryostat 2 a sealing packing 18 (Figure 3) is provided in the cryostat 2. A cavity 19 in the sealing packet 18 accommodates the throttle of the heat exchanger 3. The cryostat 2 is further provided with a coil 21 surrounding the cooled object 12. The coil 21 communicates with the cavity 19 and also with the low pressure side 7 of the heat exchanger 3.

In such a low temperature unit, the refrigerant, on passage through the throttle 20 enters the cavity 19 and thence flows into the coil 21, and absorbs heat from the object 12 being cooled, whereupon the refrigerant is returned to the low-pressure side 7 of the heat exchanger 3 for recovery.

WHAT WE CLAIM IS:—

1. A refrigerant comprising a first component and at least one other component having a higher isothermal integral throttling effect and a higher boiling point than the said first component, wherein the said other component(s) has a solidification point above the boiling point of the said first component at atmospheric pressure.

2. A refrigerant as claimed in claim 1 wherein the or each said other component is soluble in said first component at the boiling point of said first component under sub-atmospheric or atmospheric pressure.

3. A refrigerant as claimed in claim 2 wherein the said first component is nitrogen, and the said other component is methane in an amount of about 50% by volume.

4. A refrigerant as claimed in claim 1 wherein the or each said other component is solid at the boiling point of said first component under sub-atmospheric or atmospheric pressure, and in combination said other components form a eutectic mixture whose solidification point lies below the boiling point of said first component under sub-atmospheric or atmospheric pressure.

5. A refrigerant as claimed in claim 4 wherein the said first component is nitrogen, and the said other components forming a eutectic mixture having a solidification point below the boiling point of said first component under atmospheric pressure are ethane and propane, the resulting mixture having the following composition, % by volume: nitrogen 30-70; ethane 35-15, and propane 35-15.

6. A refrigerant as claimed in claim 1 wherein at least one of said other components is soluble in the said first component at the boiling point of said first component under sub-atmospheric or atmospheric pressure, and the remaining said other components are soluble only in at least one of said other said components.

7. A refrigerant as claimed in claim 6 wherein the said first component is nitrogen, and said at least one of said other components is methane, and said remaining said other components are ethane and propane, the resulting mixture having the following composition, % by volume: nitrogen 70-20; methane 10-30; ethane 10-25, and propane 10-25.

8. A refrigerant as claimed in any of claims 1 to 7 including at least one additional component having a lower isothermal integral throttling effect and a lower boiling

point than said first component, said additional component having a solidification point below the boiling point of said first component under sub-atmospheric or atmospheric pressure.

9. A refrigerant as claimed in claim 8 wherein said additional component having a boiling point below the boiling point of said first component is neon, hydrogen or helium taken in an amount of 5-40% by volume.

10. A method of cooling objects to low temperatures comprising compressing a refrigerant as claimed in any of claims 1 to 9, cooling the refrigerant in a regenerative heat exchanger, throttling the refrigerant, passing the refrigerant to an object to be cooled, and heating the refrigerant in said regenerative heat exchanger.

11. A method as claimed in claim 10 wherein said other components of the refrigerant are mixed with said first component in such concentrations that the resulting mixture is, after being throttled, in the liquid-vapour state and that the temperature to which the objects are cooled is approximately equal to the cooling temperature provided by the first component only.

12. A method of cooling objects to low temperatures in units operating on a regenerative cycle involving refrigerant throttling, comprising subjecting the refrigerant used to compression, cooling in the regenerative heat exchanger of the unit and throttling through a throttle orifice, whereupon said refrigerant is directed to an object to be cooled and thereafter heated in said regenerative heat exchanger, said refrigerant containing components having, under identical conditions, a higher isothermal integral throttling effect and a higher boiling point than those inherent in the original refrigerant, said components being further characterized in that each of said components alone has a solidification point above the boiling point of said original refrigerant under atmospheric pressure, said components being mixed with said initial refrigerant in such concentrations that the resulting mixture of said initial refrigerant and said components is, after being throttled, in the liquid-vapour state and that the temperature to which the objects are cooled in the unit using said mixure, is close or equal to the cooling temperature provided by said original refrigerant alone.

13. A refrigerant according to claim 1 substantailly as herein described.

14. A method of cooling objects to low temperatures substantially as herein described with reference to the accompanying drawings.

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1336892 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

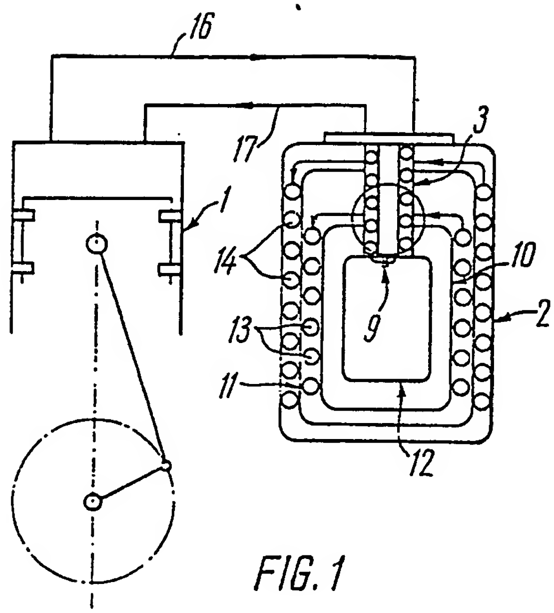

FIG. 1

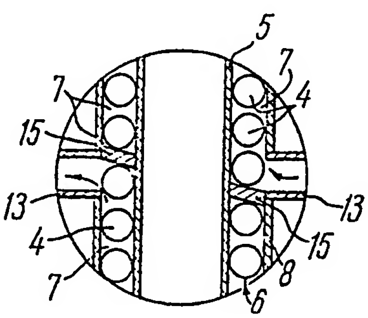

FIG. 2

1336892 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

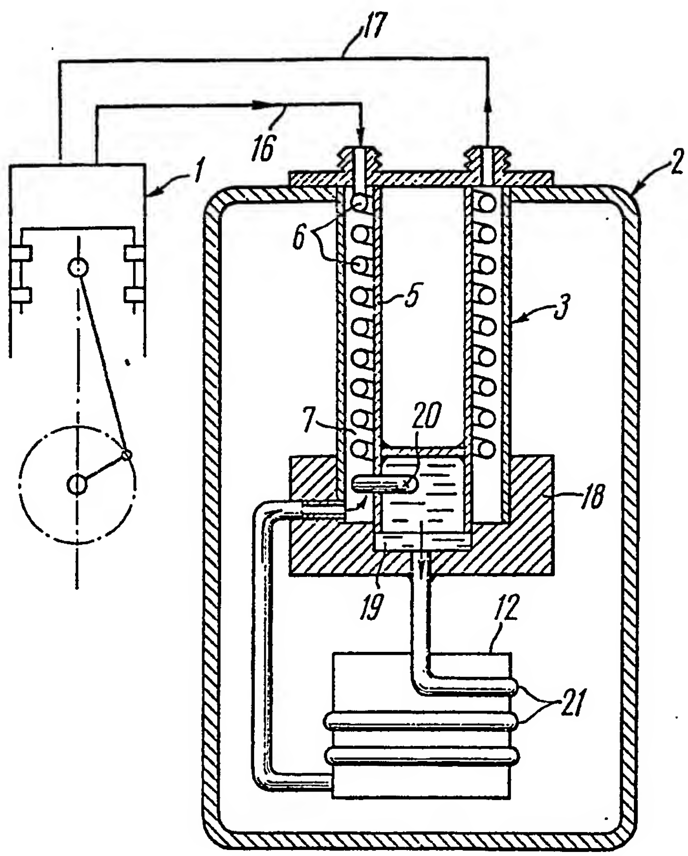

FIG. 3